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Implications of liberalization policies on government support to R&D: Lessons from electricity markets

Erkan Erdogdu *

Energy Market Regulatory Authority, Muhsin Yazıcıoğlu Cd., 51/C, 06530 Yüzüncüyıl, Ankara, Turkey

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ABSTRACT

Since the early 1980s, electricity industry reforms have been initiated in more than half of the countries in the world. Among the primary targets of these reform schemes, there has been an increase in efficiency of the sector; and it is implicitly assumed that government support to energy technology R&D will progress in line with the reform process as the former is required to sustain improved efficiency in the middle and long run. The paper reviews the relation between reform process in electricity markets and government support to energy R&D. Using panel data from 27 countries covering the period from 1974 to 2008, this study aims at finding out to what extent the expected correlation between reform process and government support to energy R&D has in practice been materialized so far. The findings suggest that, contrary to expectations, the progress toward electricity market reform is associated with reduced government support to a variety of energy R&D activities, which threatens sustainable efficiency improvements in the power industry.

Contents

1. Introduction

By the 1980s, a number of political, financial and technical factors converged and started to undermine the logic that electricity industry should be handled via a vertically integrated (and usually state-owned) monopoly [1]. Among these factors, there were ideological reasons,[1] development of gas-fired combined cycle gas turbines[2] (CCGTs), improvement in information and communication technologies, questions about the efficiency of vertically integrated utilities (whether publicly owned or regulated by public) and poor performance of existing utilities especially in developing countries. The power sector reform began in Chile in 1982 for the first time and then spread through various countries in the world especially after the 1990s. As suggested by Sioshansi [3], Dubash [4] and Reddy [5], this was a true paradigm shift. This shift has also been strongly encouraged by the World Bank, IMF and other international financial institutions. In 1992, the World Bank officially changed its

* Tel.: +90 506 3237325.
E-mail addresses: erkan@erdogdu.net, eerdogdu@epdk.org.tr

[1] In the United Kingdom, for example, privatization of state owned electricity utility reinforced the ideology of the Thatcher government and its interest in reducing the costs of domestic coal subsidies. Similar ideological and political explanations can be found from Norway to New Zealand. Hogan ([2]Hogan. Electricity market restructuring: reforms of reforms. J Regul Econ. 2002; 21:103–132.).

[2] The advent of highly efficient CCGTs made it possible to build small units in relatively short time with little risk, which eliminated the significant barriers that had previously existed to entry in power generation.

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lending policy for electricity development from traditional project lending to policy lending. That is, any country borrowing from the Bank on power projects would have to agree to move away from a "single national electricity utility as a public monopoly" and adopt ownership, structural and regulatory reforms [6]. Other international financial institutions, such as the Asian Development Bank, European Bank for Reconstruction and Development, and the Inter-American Development Bank have followed the suit [7]. Today, reforms are ongoing in many countries and reform process in the power sector is regarded as not only possible and necessary, but also inevitable.

The main aim of liberalization process in power industry has been to improve the efficiency in the sector. Besides, it is implicitly assumed that, in line with reform process, government support to R&D in energy technology will also increase as it is another component (together with reform process) of the policy aiming at increasing efficiency in electricity sector. It is argued that governments will have an incentive to engage in and increase R&D because the main source of efficiency improvement in the sector lies in long-term technical progress encouraged by R&D. Evidence suggests that electricity sector reforms can achieve (short-term) operating efficiency through cost saving and the spread of best practice. The logical addition to this argument is that liberalization will also lead to improved R&D to maintain improved efficiency in the middle and long term. In this paper, we question whether this is the case or not. We try to answer following research questions: (i) what is the impact of electricity market reforms on government support to R&D in energy technology? (ii) does liberalization effect different kinds of energy technologies (such as fossil fuel, nuclear, renewable power technologies) in different directions or does it have the same effect for all sorts of technologies? (iii) what are the other factors (apart from reform process) that influence government support to energy technology R&D and how much are they influential relative to reform process?

The paper proceeds as follows. Next section provides the conceptual framework and presents a literature review. Section 3 overviews data. Section 4 summarizes the methodological framework. Following section presents empirical analysis and discusses the results. Section 6 mentions potential limitations of the study. The last section concludes, presenting policy implications of the study.

2. Conceptual framework and literature review

Jamasb et al. [8] classify approaches to analyzing electricity reforms into three broad categories: (i) econometric methods, (ii) efficiency and productivity analysis methods, and (iii) individual or comparative case studies. They argue that econometric studies are best suited to the analysis of well-defined issues and the testing of hypotheses through statistical analysis of reform determinants and performance. According to them, efficiency and productivity analyses are suitable for measuring the effectiveness with which inputs are transformed into outputs, relative to best practice. Jamasb et al. [8] also maintain that single or multi-country case studies are suitable when in-depth investigation or qualitative analysis is needed. Within this classification, our study well suits the first category; that is, an econometric study focusing on cross-country evidence on the impact of electricity market reforms.

The link between market liberalization policies and government support to R&D is one of the least explored areas in the literature; and one between power market reforms and government support to energy R&D is not explored at all. So, in this section we cannot cite previous empirical studies similar to ours as, to our best knowledge, this is the first study in this area. Instead, we present non-econometric studies on the relationship between liberalization and government support to R&D.

Dooley [9] argues that many advanced industrialized nations are substantially reducing their national (public and private) investments in energy R&D, driven in part by changes occurring as a result of the deregulation of these nations' energy sectors. In particular, he continues, funding for strategic energy R&D aimed at developing future energy supply options (e.g., fusion, fission, 'clean' fossil energy, renewable energy) has been decreased substantially in both the public and private sectors in many of these nations. He also maintains that these trends are starting to be seen in the United States as it moves towards the deregulation of the nation's utilities. The magnitude of the reductions in support for energy R&D in the public and private sectors and the shift towards decidedly shorter-term R&D has profound implications for nations approaching deregulation. He concludes though utility customers may be short-term winners from the deregulation of utilities by paying less for energy, a national failure to invest in energy R&D is very likely to have long-term negative impacts on national energy sectors, the economies, and environmental wellbeing.

Aggarwal [10] analyses the effects of the deregulation policy introduced in India in the mid-1980s on the relationship between technology imports and in-house R&D efforts. Using statistical techniques, Aggarwal [10] examines the interactions between policy regime, economic environment and the determinants of inter-industry variation in technology imports in Indian manufacturing. In doing so, he introduces R&D efforts as one of the main determinants. The empirical results reveal that deregulation promoted complementarity between technology imports and R&D efforts significantly. The results also suggest that after deregulation, the impact of product differentiation, demand conditions and technology-related factors increased significantly in determining the inter-industry patterns of technology imports. Thus, unlike in a regulated regime where technology imports are viewed important for filling gaps in domestic technological capabilities, in a deregulated regime technology upgrade seems to be the major role of technology imports.

Calderini and Garrone [11] investigate the relationship between market structure and the composition of R&D activities. They present an empirical model to demonstrate that when market structure is shuffled by an institutional discontinuity, such as liberalization, basic and applied activities respond in opposite ways: the former decrease whereas the latter increase. As a consequence, they argue, market turmoil is likely to provide firms with short-term incentives, shifting the allocation of resources towards applied and development activities. They tested the model on a data set including innovation measures from the incumbent public telecommunications operators of 17 European countries. They conclude that the dynamics outlined in the model are likely to prevent firms (industries) sustaining an appropriate rate of innovative activity.

Katrak [12] focuses on concerns that India's recent economic liberalization measures will result in a neglect of the development of indigenous technologies and will make increasing use of imported technologies and/or of standardized technologies. Katrak [12] argues that the comparative advantages of the different types of technologies will depend on certain enterprise-level characteristics, including age and size, and consequently enterprises that use the technologies based on their in-house R&D efforts may perform well even under a liberalized regime. Empirical tests, using data of enterprises in three major industry groups, gave results consistent with these arguments. The paper finds that over the period 1991–1998 the growth performance of enterprises that make products based on their in-house R&D efforts have compared favorably with those of other enterprises, in two of the industries.

Bowonder and Satish [13] provide another review of impact of liberalization polices on R&D in India. They argue that before the start of liberalization in 1991 the Indian economy was an inward looking system under government control but following the drive to liberalization it has changed in many ways. For a start, the national system of innovation has been affected by exposure to market forces. Global firms have founded R&D centers in India and large private firms have increased spending on R&D. They also state that patentable innovations have shown a sharp rise since the opening up of the economy. As a percentage of GNP, however, R&D expenditure is still much lower than that observed in countries such as China, Taiwan, and Brazil. They conclude that the Indian share of world trade is very low, and so there is a need for further expansion of R&D initiatives.

Runci and Dooley [14] review R&D spending on energy technologies in various countries. They find that the majority of the countries with high R&D spending on energy technologies made large cuts in energy R&D support during the 1990s. They find that restructuring and deregulation of the energy industries have been strongly correlated with energy R&D funding cuts; and France and Japan are the only major energy R&D-performing countries that have not yet restructured their energy industries.

Jamasb et al. [15] provides another case study that presents the relationship between liberalization an R&D. Their paper is a critical assessment of the current balance of efforts towards energy R&D and the promotion of low-carbon electricity technologies in the UK. They review the UK's main technological options and their estimated cost ranges in the medium term. They contrast the energy R&D spending with the current and expected future cost of renewable promotion policies and point out the high cost of carbon saving through existing renewable promotion arrangements. They note that liberalization of the electricity sector has had significant implications for the landscape of energy R&D in the UK. They argue that there is a need for reappraisal of the soundness and balance of the energy R&D and renewable capacity deployment efforts towards new energy technologies. They suggest that the cost-effectiveness of UK deployment policies needs to be more closely analyzed as associated costs are non-trivial and expected to rise. They also make a case for considering increasing the current low level of energy R&D expenditure. They argue that much of energy R&D is a public good and we should consider whether the current organization of R&D effort is fit for purpose. They conclude that it is important to build and maintain the research capability in the UK in order to absorb spillovers of technological progress elsewhere in the world.

Finally, Jamasb and Pollitt [16] explore the reasons why electricity sector liberalization has coincided with a significant decline in R&D spending. They review the industrial organization literature on R&D and innovation to explore the likely causes of the decline in R&D spending in the electricity sector. Meanwhile, they argue, R&D productivity and innovative outputs in utilities and equipment suppliers appear to have improved; however, a lasting decline in R&D expenditure can have a negative long-term effect on technological progress and innovation in the sector. They conclude that the decline in R&D could have been predicted from the literature. They also discuss the need to reorient the post-liberalization technology policy.

Based on this brief literature review, we may argue that present literature is limited to case studies that focus on a single country and anecdotal discussions of possible implications of liberalization process on R&D activities. Cross-country econometric evidence on the impact of the liberalization process on R&D spending is nonexistent and will take more time to emerge. There exists a huge research gap in this area and this paper constitutes one of the first efforts to fill this gap using cross-country empirical data.

3. Overview of data

Our data set is based on a panel of 27 countries[3] for a period beginning in 1974 and extending through 2008. Selection of time period and countries in the sample is determined by data availability. Because of the missing observations, our panel is unbalanced. Since our panel dataset includes data on 27 countries for 35 years, the possible maximum number of observations for each variable is 945 (27×35).

The variables used in the study are total energy R&D budget, R&D budget for energy efficiency, R&D budget for fossil fuels, R&D budget for nuclear energy, R&D budget for renewable energy sources, electricity market reform score, energy self-sufficiency, energy intensity of GDP and real GDP per capita.

The data on government energy technology R&D budgets are obtained from IEA [17]. Budgets are available for several R&D activities: energy efficiency, fossil fuels, renewable energy sources and nuclear energy. Data for 27 IEA member countries are available. Fig. 1 presents government energy technology R&D budgets in 2007. As can be seen in the figure, US, Japan, France and Korea are responsible for most of the government energy technology R&D spending in 2007.

Electricity market reform score variable takes the values from 0 to 8; depending on how many of the following reform steps have been taken in each country and each year: (1) introduction of independent power producers, (2) corporatization of state-owned enterprises, (3) law for electricity sector liberalization, (4) introduction of unbundling, (5) establishment of electricity market regulator, (6) introduction of privatization, (7) establishment of wholesale electricity market, and (8) choice of supplier. To build this variable, we created 8 dummy variables for each of the reform steps mentioned above and calculated the total number of reform steps taken in each country and each year. Dummy variables for reform steps are created based on the data collected and cross-checked from various international and national energy regulators' web sites.[4] Fig. 2 presents the changes in reform score variable for the countries in our sample from 1990 to 2008.

The variable "energy self-sufficiency" is calculated by dividing primary energy production by primary energy supply for each country and each year. Energy intensity of GDP is used to measure how much energy is used to generate a unit of GDP. It is calculated by dividing primary energy supply by total GDP. Fig. 3 shows these two variables for 2008. The data on primary energy production and primary energy supply come from IEA [18], while data on GDP and real GDP per capita are obtained from CIC [19] and World Bank [20]. As shown in the figure, only Australia, Canada, Denmark and Norway are self-sufficient in energy while Canada, Finland, Czech Republic, Korea and USA are the countries with highest GDP energy intensity figures. Table 1 shows descriptive statistics of the variables in our analysis.

4. Methodology

As underlined by Jamasb et al. [8], there is a lack of generally accepted and measured indicators for monitoring the progress, impacts, and performance of electricity sector reforms. Since the aim of this paper is to propose a framework for analyzing the

[3] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, South Korea, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.

[4] The full list of sources from which data are obtained can be found at IERN web site (http://www.iern.net).

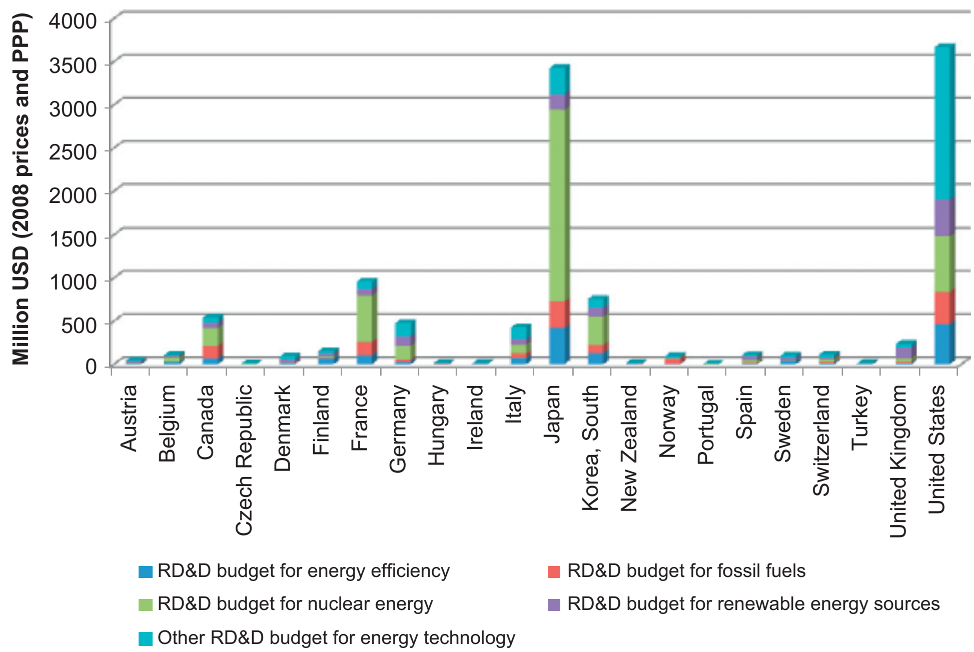

Fig. 1. Government energy technology R&D budgets in 2007.

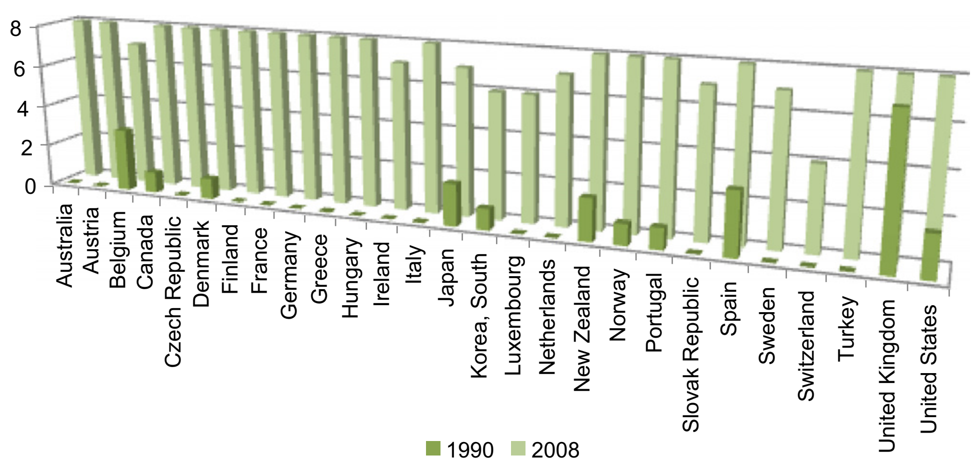

Fig. 2. Electricity market reform scores in 1990 and 2008.

impact of the power market reforms on government support to energy R&D, we face with the same problem. That is, we need to, first, evaluate possible impact of reforms on government support to energy R&D; second, decide which indicators to use in our study and; finally, specify methods to measure them. Let me focus on these tasks one by one.

To our best knowledge, no applied study has been done so far on the possible implications of the power market reform process on government support to energy R&D. Therefore, we cannot find empirical evidence in the literature for or against the positive or negative impact of the reform initiatives on government support to energy R&D. To carry out the analysis suggested above, we need to decide which indicators to be used in the study. Since we are interested in the impact of the power market reforms on government support to energy R&D, we need variables representing government spending in various energy R&D activities and a variable representing the scale and intensity of the reform. In addition to these variables, we also utilize a set of control variables (GDP per capita, energy intensity of GDP, energy self-sufficiency), which are assumed to be endogenous to reform process and explain a portion of the variations in government support to energy R&D. Another challenge we face in this study relates to the measurement of the variables. For an indicator to be useful it needs to be based on a clear definition and to be measurable. This is equally important whether it is expressed in physical, monetary or qualitative terms. In fact, most of the economic and industry indicators in our study are measured in some form of monetary or physical unit; and therefore, easy to include into the study. However, the extent and scope of electricity reforms are not quantifiable in physical or monetary units. The main electricity reform measures, such as privatization, unbundling of functions, wholesale markets and independent regulation, are generally established gradually and have a qualitative dimension. Accounting for these measures with the use of dummy variables, as is sometimes done, does not reflect extent or intensity. To overcome this problem, as discussed in Jamasb et al. [8], a practical approach has been to construct a power market reform score variable. In this study, we adopt this approach and form a reform indicator.

It is almost impossible to observe the real impact of power market reforms on government support to energy R&D without separating the effects of market reform from other country specific

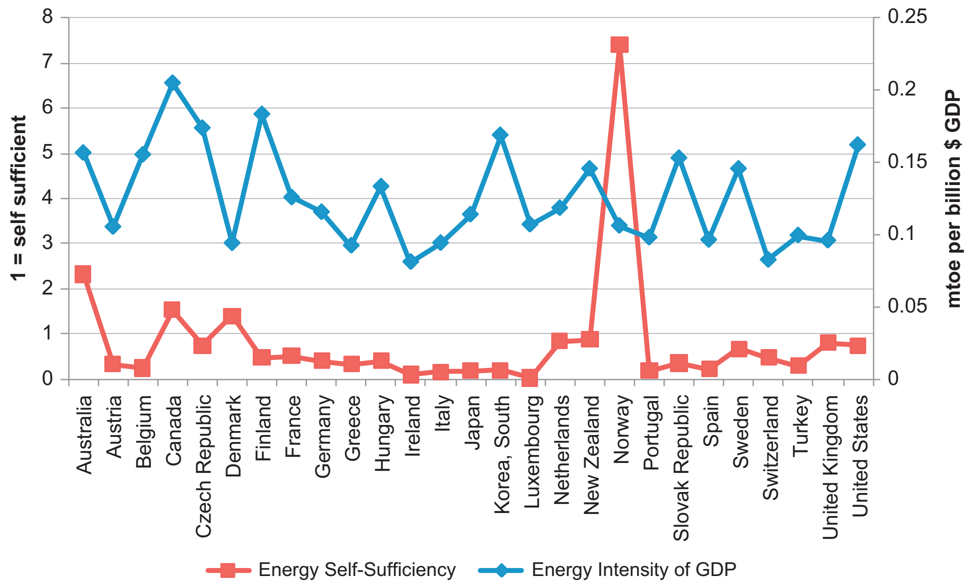

Fig. 3. Energy self-sufficiency and energy intensity of GDP in 2008.

Table 1
Descriptive statistics of the variables in the model.

Variables (units)	No. of obs.	No. of countries	Mean	Std. dev.	Min.	Max.
Total energy R&D budget (million $, 2008 prices and PPP)	671	25	581	1,163	0	9,022
R&D budget for energy efficiency (million $, 2008 prices and PPP)	675	26	52	112	0	696
R&D budget for fossil fuels (million $, 2008 prices and PPP)	679	25	74	186	0	1,924
R&D budget for nuclear energy (million $, 2008 prices and PPP)	679	26	308	660	0	4,294
R&D budget for renewable energy sources (million $, 2008 prices and PPP)	691	27	50	124	0	1,529
Reform score [0–8]	945	27	2.65	3.22	0	8
Energy self-sufficiency (1 = self sufficient)	945	27	0.73	1.18	0.001	9.45
Energy intensity of GDP (mtoe per billion $ GDP)	916	27	0.29	0.18	0.08	1.26
Real GDP per capita (current international $ and PPP)	916	27	17,625	11,123	1,180	88,335

features. Therefore, we specify our dependent variables (that is, government support to various energy-related R&D activities) as a function of (i) electricity market reform score (a comparable cross-country reform indicator), (ii) a set of controls (GDP per capita, energy intensity of GDP, energy self-sufficiency), (iii) country-specific effects (these are assumed to be exogenous and to exist independently of reform process, but may explain a portion of the variation in government support to energy R&D) and (iv) other unobserved variables that influence government support to energy R&D. These variables are then used in panel regressions to assess their impact on variables we are interested in. In panel regressions, the exploitation of both cross-country and time-series dimensions of the data allows for control of country-specific effects. Apart from reform process; government support to energy R&D in a specific country and year may be influenced by GDP per capita, energy intensity of GDP and energy self-sufficiency. In our model, we include all these variables in order to isolate the effect of the reform on government support to energy R&D.

In this paper, we formulate regression equations as below to analyze the impact of electricity industry reform on government support to energy R&D.

$$Y_{it} = \beta_1 + \sum_{j=2}^{k} \beta_j X_{jit} + \sum_{p=1}^{s} \gamma_p Z_{pi} + \delta t + \varepsilon_{it} \quad (1)$$

In the model, i and t represent unit of observation and time period, respectively. j and p are indices used to differentiate between observed and unobserved variables. X_{ji} and Z_{pi} represent observed and unobserved variables, respectively. X_{ji} includes both reform variable and control variables. Y_{it} is dependent variable.ε_{it} is the disturbance term and t is time trend term. Because the Z_{pi} variables are unobserved, there is no means of obtaining information about the $\sum \gamma_p Z_{pi}$ component of the model. For convenience, we define a term α_i, known as the unobserved effect, representing the joint impact of the Z_{pi} variables on Y_{it}. So, our model may be rewritten as follows:

$$Y_{it} = \beta_1 + \sum_{j=2}^{k} \beta_j X_{jit} + \alpha_i + \delta t + \varepsilon_{it} \quad (2)$$

Now, the characterization of the α_i component is crucially important in the analysis. If control variables are so comprehensive that they capture all relevant characteristics of the individual, there will be no relevant unobserved characteristics. In that case, the α_i term may be dropped and pooled data regression (OLS) may be used to fit the model, treating all the observations for all time periods as a single sample. However, since we are not sure whether control variables in our models capture all relevant characteristics of the countries, we cannot directly carry out a pooled data regression of Y on X. If we were to do so, it would generate an omitted variable bias. Therefore we prefer to use either a fixed effects (FE) or random effects (RE) regression. In FE model, the country-specific effects (α_i) are assumed to be the fixed parameters to be estimated. In RE model, the country-specific effects

(α_i) are treated as stochastic. The fixed effect model produces consistent estimates, while the estimates obtained from the random effect model will be more efficient. Since we cannot be sure whether the observations in our model may be described as being a random sample from a given population, we cannot directly decide which regression specification (FE or RE) to use. It will be decided in the course of the analysis based on Hausman test.

5. Empirical analysis and discussion of the results

Throughout our analysis, we estimated five models to explain the impact of power market reforms on government spending in various energy R&D activities. Since using logarithms of variables enables us to interpret coefficients easily and is an effective way of shrinking the distance between values, we transform variables representing government spending in various energy R&D activities and GDP per capita variable into logarithmic form and use these new transformed variables in our models.

We perform the empirical analysis by estimating the specification given in Eq. (2) for each model.[5] However, as mentioned before, we cannot directly decide which regression specification (FE or RE) to use. Therefore, we apply Hausman test for fixed versus random effects in each model. To perform this test, we first estimate the fixed effects model (which is consistent) and store the estimates, then estimate the random-effects model (which is efficient) and run the test. Since we prefer 5% significance level, any p-value less than 0.05 implies that we should reject the null hypothesis of there being no systematic difference in the coefficients. In short, Hausman test with a p-value up to 0.05 indicates significant differences in the coefficients. Therefore, in such a case, we choose fixed effects model. However, if p-value from Hausman test is above 0.05, we cannot reject the null hypothesis of there being no systematic difference in the coefficients at 5% level. In such cases, Hausman test does not indicate significant differences in the coefficients. Therefore, we provisionally choose random effects. After that, we apply Breusch and Pagan Lagrangian Multiplier (BPLM) test for random effects in order to decide on using either pooled OLS or random effects in our analysis. This test is developed to detect the presence of random effects. In this test, the null hypothesis is that variances of groups are zero; that is, there is no unobserved heterogeneity, all groups are similar. If the null is not rejected, the pooled regression model is appropriate. That is, if the p-value of BPLM test is below 0.05, we reject the null, meaning that random effects specification is the preferred one. If it is above 0.05, we prefer pooled OLS specification to carry out our regression. Table 2 presents estimation results for each model, including estimation output, number of observations and countries included in the model estimation, results of Hausman and BPLM tests and preferred specifications based on these tests.

It is not easy to draw conclusions about the impact of extensive electricity market reforms in various countries from empirical work that focuses on a single market or from other country-specific anecdotal discussion of reform processes because neither type of study distinguishes the effects of reform from country-specific features. Therefore, our empirical approach was to take advantage of the diversity in electricity reform patterns in various countries and to control for a number of potential explanatory variables to predict the impact of electricity market reforms on government support to energy R&D. Panel analysis of the trends in government support to energy R&D (using reform variables, country macroeconomic and other structural features) offers objective evidence on the observed impact of reforms at a macro level.

When we look at the results from this study, we see that electricity market reform score variables have a negative relationship with variables representing government support to various energy R&D activities. Our interpretation of the results in detail is as follows:

(1) In the first model, our empirical findings support the idea that reform process causes a decline in total government energy R&D spending. On average, government of a country with no reform at all allocates 0.7% more budget on energy R&D compared to that of a country where all reforms steps are taken. On the other hand, energy self-sufficiency, energy intensity of GDP and GDP per capita seem to be both positively correlated with government energy R&D spending and much more influential on government support to energy R&D compared to reform process. That is to say, countries supplying a higher share of their energy needs from domestic sources and having more energy intense GDPs and those with higher per capita income invest more in R&D. For instance, 10% increase in GDP per capita results in 2.7% increase in government budget for R&D related activities.
(2) The trends in R&D budgets for renewable energy sources (Model 2) also follow the general tendency with the exception that there is a negative relationship between R&D budgets for renewable energy sources and energy intensity of GDP. That is, countries with more energy intense GDPs spend less money for renewable energy R&D. This conclusion seems reasonable when we take into account the fact that countries with more energy intense GDPs are interested in technologies that are capable of producing large amount of energy to meet their significant energy needs (rather than renewable technologies that produce clean but lower amounts of energy).
(3) In the third model, we see that nuclear power R&D spending also follows general trends. The only exception is that there is a negative relationship between income level and R&D spending on nuclear technology, meaning that as countries get richer they tend to abandon nuclear technology.
(4) R&D spending on fossil fuel technologies is completely in line with our general observations; however, the positive relationship between R&D spending on fossil fuel technologies and energy intensity of GDP is not statistically significant even at 10% level.
(5) In the last model, we again see a negative relationship between R&D spending on energy efficiency and reform process. On the other hand, we could not detect a statistically significant impact of income level on energy efficiency R&D spending. Besides, our results imply that energy self-sufficient countries spend less on energy efficiency related technologies. Similarly, our findings suggest that countries with more energy intense GDPs allocate a lower amount of budget on energy efficiency related technologies than those with less energy intense GDPs.
(6) We see that country specific features tend to have a high power in explaining government support to energy R&D spending in almost all models.

To sum up, our results reveal that the progress toward the electricity market reform is associated with less government spending on energy technology R&D. However, although our conclusions verify the idea that electricity market reform process (with privatization, liberalization and vertical disintegration) discourages government energy R&D spending; it does not necessarily involve a judgment on the overall success or failure of the reform process. It may be argued that the reform process has just started or is still under progress in many countries

[5] Throughout the paper, model estimations are carried out and cross-checked by StataSE 11.1 and Eviews 7.1.

Table 2
Estimation results.

Models	Dependent variable	Explanatory variables	Coef.	Std. err.	*t*-stat.	*p*-value	Number of countries	Number of observations	Hausman test		Preferred specification
									Statistic	*p*-value	
Model 1	Log of total energy R&D budget	Reform score [0–8]	−0.089***	0.012	−7.600	0.00	25	670	6616.52	0.0000	Fixed effects
		Energy self-sufficiency	0.230***	0.034	6.810	0.00					
		Energy intensity of GDP	0.691**	0.313	2.210	0.03					
		Log of GDP per capita	0.268**	0.115	2.340	0.02					
		Constant	2.087*	1.152	1.810	0.07					
Model 2	Log of R&D budget for renewable energy sources	Reform score [0–8]	−0.055***	0.018	−3.080	0.00	27	679	3107.53	0.0000	Fixed effects
		Energy self-sufficiency	0.143***	0.054	2.670	0.01					
		Energy intensity of GDP	−1.144**	0.479	−2.390	0.02					
		Log of GDP per capita	0.397**	0.175	2.260	0.02					
		Constant	−0.820	1.768	−0.460	0.64					
Model 3	Log of R&D budget for nuclear energy	Reform score [0–8]	−0.070***	0.016	−4.340	0.00	26	613	4638.88	0.0000	Fixed effects
		Energy self-sufficiency	0.299***	0.054	5.500	0.00					
		Energy intensity of GDP	0.904**	0.423	2.140	0.03					
		Log of GDP per capita	−0.530***	0.160	−3.320	0.00					
		Constant	8.477***	1.609	5.270	0.00					
Model 4	Log of R&D budget for fossil fuels	Reform score [0–8]	−0.168***	0.024	−7.110	0.00	25	636	4746.69	0.0000	Fixed effects
		Energy self-sufficiency	0.246***	0.079	3.120	0.00					
		Energy intensity of GDP	0.973	0.613	1.590	0.11					
		Log of GDP per capita	0.479**	0.235	2.040	0.04					
		Constant	−2.200	2.357	−0.930	0.35					
Model 5	Log of R&D budget for energy efficiency	Reform score [0–8]	−0.056***	0.020	−2.860	0.00	25	641	2530.39	0.0000	Fixed effects
		Energy self-sufficiency	−0.251***	0.066	−3.800	0.00					
		Energy intensity of GDP	−1.566***	0.538	−2.910	0.00					
		Log of GDP per capita	−0.055	0.197	−0.280	0.78					
		Constant	3.989**	1.987	2.010	0.05					

*** Coefficients that are significant at 1% level.
** Coefficients that are significant at 5% level.
* Coefficients that are significant at 10% level.

and today it is too early to measure its impact. This and similar arguments cannot be rejected straight away. Today, what we may argue correctly is that, as a result of reforms, a decline in government spending on energy technology R&D has been observed so far.

6. Limitations of the study

The research may have a number of limitations that we acknowledge. In fact, we have no reason to believe that any of these limitations should be existent in our analysis, but cannot of course rule them out.

To begin with, like all other econometric studies on electricity reform, the issue of endogeneity may be raised in our study. The analysis dealt to some extent with this potential problem by including country and year fixed effects. The country fixed effects control for country-specific propensities to reform and matters such as institutional characteristics, and year fixed effects control for any general trend in the reform of electricity sector.

Second shortcoming may originate from the lack of data. Due to limited nature of our data set, we could not properly account for the impact of some other variables on government support to energy R&D like institutional characteristics, technological innovations and changes to regulatory practices. It should also be added that a more accurate assessment (incorporating private industry support) of total national R&D efforts directed at energy technology is difficult to obtain due to a lack of data and to variations in the way private industry's energy technology R&D is measured from one country to another. Besides, with liberalization process, data on energy R&D in the private sector has become more commercially sensitive and, therefore, less available. Hence, in this study, we focused only on public R&D spending and ignored private contribution into energy technology R&D.

Some aspects of electricity reforms are not readily quantifiable in physical or monetary units. The main issue is that simple observation of the fact that some reform steps have been taken does not reflect their characteristics and extent [8]. That is to say, objective comparisons across countries are inherently difficult in any study and our analysis is not an exception. The main steps of electricity reform process are usually established progressively and have a qualitative dimension. Accounting for these measures with the use of dummy variables does not reveal their true scope or intensity. To lessen the impact of this drawback, we did not use individual dummy variables for reform elements in this study. Instead, we constructed a power market reform score indicator to reflect scale and scope of the reform process. Although such an approach seems a practical and reasonable representation of the reform process, we cannot argue that we reflected all characteristics of various reform processes in our study.

Finally, any measurement error and omission of explanatory variables may bias estimates of all coefficients in the models. However, in our study, omitted variables may be captured at least in part by the country-specific effects, mitigating the potential for bias.

7. Policy implications and conclusion

Energy technologies are the primary determinants of energy availability, fuel choice, end-use efficiency, and the amount of GHG emissions; and energy R&D is the vehicle by which new technologies become available. To the extent that energy technologies increase or reduce society's range of energy choices, energy R&D is a matter of high importance. In the study, we used empirical econometric models to observe the impact of electricity market reforms on government energy technology R&D spending. Panel data from 27 countries covering the period from 1974 to 2008 were employed. We found that the progress toward the electricity market reform is associated with less government spending on energy technology R&D. The most important policy implication of this conclusion is that countries implementing reforms in their electricity industries should maintain and increase energy technology R&D budgets as, without R&D, it is very difficult (if not impossible) to maintain increased levels of efficiency, obtained as a result of reform process, in the middle and long run. Reforms may increase efficiency in the short run by reducing costs and removing cross-subsidies; however, it is R&D that keeps and advances efficiency in the long term.

While our analysis serves as one of the first steps in assessing the impact of reform process on R&D in the energy industry, there is still much room for improvement within the models and data presented in this paper. The analysis can be enhanced by incorporating private R&D spending into the analysis. Besides, as done in many other similar studies, we treated large countries like United States, Japan, Canada and France in the same way as smaller countries like Czech Republic and Hungary. In the future studies, new methods should be developed to reflect the impact of the size and scale of the countries. More to the point, today there are data on electricity market reforms going back about three decades and available data start to let us meaningfully establish which market model and industry structure optimize R&D spending in the power market.

This study tried to fill the gap in the literature by offering a macro level econometric analysis on the possible effects of reform process on public energy technology R&D spending. Even with this study, it is obvious that present econometric evidence on the impact of the reform process is quite limited. So, there is a definite need for continued analyses of the effect of reforms in the electricity industry. Much work needs to be done and there are ample opportunities for research in this area. In many countries, power market reform is still an on-going process, a fact that also underlines the need for continued and up-to-date study. Besides, we admit that power market reform is complex and the evidence is difficult to evaluate. An exact reckoning of the long-term effects of reforms on R&D will require much additional study over longer periods of time.

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